Exploring the Nature of Science

Using the *Atlas of Science Literacy* and Other Education Resources from AAAS Project 2061

Project 2061
AAAS

About Project 2061

Project 2061 began its work in 1985—the year Halley's Comet was last visible from Earth. Children starting school then and now will see the return of the Comet in 2061—a reminder that today's education will shape the quality of their lives as they come of age in the 21st century amid profound scientific and technological change.

A long-term initiative of the American Association for the Advancement of Science (AAAS), Project 2061's mission is to help all Americans become literate in science, mathematics, and technology. To that end, Project 2061 conducts research and develops tools and services that educators, researchers, and policymakers can use to make critical and lasting improvements in the nation's education system.

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www.Project2061.org

About AAAS

The American Association for the Advancement of Science (AAAS) is the world's largest general scientific society, and publisher of the journal, *Science* (www.sciencemag.org) as well as *Science Translational Medicine* (www.sciencetranslationalmedicine.org) and *Science Signaling* (www.sciencesignaling.org). AAAS was founded in 1848, and includes some 262 affiliated societies and academies of science, serving 10 million individuals. *Science* has the largest paid circulation of any peer-reviewed general science journal in the world, with an estimated total readership of 1 million. The non-profit AAAS (www.aaas.org) is open to all and fulfills its mission to "advance science and serve society" through initiatives in science policy; international programs; science education; and more. For the latest research news, log onto EurekAlert!, www.eurekalert.org, the premier science-news Web site, a service of AAAS.

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About this Guide

Dear colleague:

In his 2008 book *Why Science?* physicist and science writer James Trefil defines science literacy as “the matrix of knowledge needed to understand enough about the physical universe to deal with issues that come across the horizon of the average citizen, in the news or elsewhere.” This definition reflects a growing consensus, shared by Project 2061, on what it means to be science literate and the ways in which science knowledge and habits of mind can empower individuals.

In addition to the knowledge that science provides about the physical and man-made world, people also need an understanding of the scientific endeavor itself: the assumptions scientists share about the nature of the world and what can be learned from it, their reliance on evidence and logical arguments to justify claims, and the significant role of science in informing invention and public policy. For example, although a new theory may receive considerable attention, it rarely gains widespread acceptance in the scientific community until its advocates can show it is supported by evidence, is logically consistent with other principles that are not in question, explains more than its rival theories, and has the potential to lead to new knowledge.

This booklet offers an introduction to Project 2061’s education resources related to understanding the nature of science and developing the habits of mind needed to use that understanding for personal and social purposes. These resources include a selected set of strand maps from our two-volume *Atlas of Science Literacy* and excerpts from *Science for All Americans* that focus on basic values and beliefs that make up the scientific world view and tools and ways of thinking and communicating that are central to the practice of science and the use of scientific knowledge. To provide a better sense of how educators might evaluate students’ understanding of important ideas about the nature and practice of science, we include sample test questions for assessing their knowledge. And for those who are interested in further exploration of the nature of science, we suggest several highly recommended trade books.

We hope this booklet serves as a helpful guide. Please let us know how you have used it; you can send your comments and suggestion to project2061@aaas.org. We look forward to hearing from you.

Sincerely,

Jo Ellen Roseman

Jo Ellen Roseman, Ph.D.
Director, AAAS Project 2061

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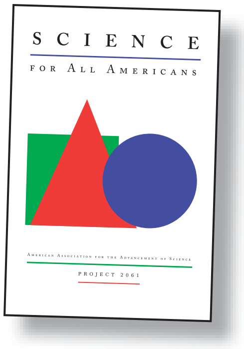
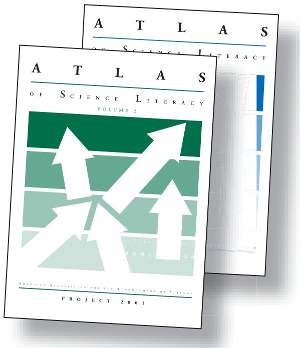


About *Science for All Americans*

With expert panels of scientists, mathematicians, and technologists, Project 2061 set out to identify what was most important for the next generation to know and be able to do in science, mathematics, and technology—what would make them science literate. *Science for All Americans* defines a science literate person as one who:

- is familiar with the natural world.
- understands some of the key concepts and principles of science.
- has a capacity for scientific ways of thinking.
- is aware of some of the important ways in which mathematics, technology, and science depend on one another.
- knows that science, mathematics, and technology are human enterprises and what that implies about their strengths and weaknesses.
- is able to use scientific knowledge and ways of thinking for personal and social purposes.

Published in 1989, *Science for All Americans* lays the groundwork for state and national science standards and is one of the most influential books in the field of science education. Available from Oxford University Press, 1-800-451-7556 or online at http://www.project2061.org/publications/sfaa/online/.



About *Atlas of Science Literacy*

Atlas of Science Literacy displays in map-like form how key ideas related to important topics in science, mathematics, and technology connect with each other and from one grade to the next. *Atlas, Volume 1*, published in 2001, gave educators access to conceptual strand maps for nearly 50 topics. *Atlas, Volume 2*, published in 2007, completes the set with another 44 maps.

Each conceptual strand map in *Atlas* displays the benchmarks—from primary school to high school—that are most relevant to understanding a particular topic along with earlier benchmarks they build on and later benchmarks they support. The ideas and skills presented in the maps are specific goals for student learning and are derived from both *Science for All Americans* and its companion volume *Benchmarks for Science Literacy* (also available from Oxford University Press at 1-800-451-7556 or online at http://www.project2061.org/publications/bsl/online/bolintro.htm). Each map is accompanied by commentary on the topic, on features of the map itself, and on any topic-specific research on student learning.

Connections

Connections between benchmarks are based on the logic of the subject matter and, insofar as possible, on the published research into how students learn—both in general and with regard to specific concepts. A connection between two benchmarks, represented in the maps by an arrow, means that one "contributes to achieving" the other. The occasional double-headed arrow implies mutual support.

Strands

Strands are pointed out at the bottom of each map to help the reader find things in the map and get a sense of its content. Where possible, relevant benchmarks are positioned in a column above each label.

Grade Ranges

Grade ranges are delineated by horizontal gray lines. Benchmarks may be achieved in higher or lower grades depending on students' interests, abilities, and experience.

Connections to Other Maps

Connections to other maps are identified to help the reader keep in mind the notion of a larger set of ideas from which a subset of ideas has been teased out for each topic.

See p. 31 for information on ordering both *Atlas 1* and *Atlas 2*.

From *Science for All Americans,*
Chapter 1: The Nature of Science

Over the course of human history, people have developed many interconnected and validated ideas about the physical, biological, psychological, and social worlds. Those ideas have enabled successive generations to achieve an increasingly comprehensive and reliable understanding of the human species and its environment. The means used to develop these ideas are particular ways of observing, thinking, experimenting, and validating. These ways represent a fundamental aspect of the nature of science and reflect how science tends to differ from other modes of knowing.

It is the union of science, mathematics, and technology that forms the scientific endeavor and that makes it so successful. Although each of these human enterprises has a character and history of its own, each is dependent on and reinforces the others. Accordingly, the first three chapters of recommendations draw portraits of science, mathematics, and technology that emphasize their roles in the scientific endeavor and reveal some of the similarities and connections among them.

THE SCIENTIFIC WORLD VIEW

Scientists share certain basic beliefs and attitudes about what they do and how they view their work. These have to do with the nature of the world and what can be learned about it.

The World Is Understandable

Science presumes that the things and events in the universe occur in consistent patterns that are comprehensible through careful, systematic study. Scientists believe that through the use of the intellect, and with the aid of instruments that extend the senses, people can discover patterns in all of nature.

Science also assumes that the universe is, as its name implies, a vast single system in which the basic rules are everywhere the same. Knowledge gained from studying one part of the universe is applicable to other parts. For instance, the same principles of motion and gravitation that explain the motion of falling objects on the surface of the earth also explain the motion of the moon and the planets. With some modifications over the years, the same principles of motion have applied to other forces—and to the motion of everything, from the smallest nuclear particles to the most massive stars, from sailboats to space vehicles, from bullets to light rays.

Scientific Ideas Are Subject To Change

Science is a process for producing knowledge. The process depends both on making careful observations of phenomena and on inventing theories for making sense out of those observations. Change in knowledge is inevitable because new observations may challenge prevailing theories. No matter how well one theory explains a set of observations, it is possible that another theory may fit just as well or better, or may fit a still wider range of observations. In science, the testing and improving and occasional discarding of theories, whether new or old, go on all the time. Scientists assume that even if there is no way to secure complete and absolute truth, increasingly accurate approximations can be made to account for the world and how it works.

Scientific Knowledge Is Durable

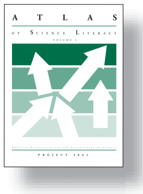
Although scientists reject the notion of attaining absolute truth and accept some uncertainty as part of nature, most scientific knowledge is durable. The modification of ideas, rather than their outright rejection, is the norm in science, as powerful constructs tend to survive and grow more precise and to become widely accepted. For example, in formulating the theory of relativity, Albert Einstein did not discard the Newtonian laws of motion but rather showed them to be only an approximation of limited application within a more general concept. (The National Aeronautics and Space Administration uses Newtonian mechanics, for instance, in calculating satellite trajectories.) Moreover, the growing ability of scientists to make accurate predictions about natural phenomena provides convincing evidence that we really are gaining in our understanding of how the world works. Continuity and stability are as characteristic of science as change is, and confidence is as prevalent as tentativeness.

Science Cannot Provide Complete Answers to All Questions

There are many matters that cannot usefully be examined in a scientific way. There are, for instance, beliefs that—by their very nature—cannot be proved or disproved (such as the existence of supernatural powers and beings, or the true purposes of life). In other cases, a scientific approach that may be valid is likely to be rejected as irrelevant by people who hold to certain beliefs (such as in miracles, fortune-telling, astrology, and superstition). Nor do scientists have the means to settle issues concerning good and evil, although they can sometimes contribute to the discussion of such issues by identifying the likely consequences of particular actions, which may be helpful in weighing alternatives.

THE NATURE OF SCIENCE

SCIENTIFIC WORLD VIEW (1A)



Scientists share certain basic assumptions about the nature of the world and what can be learned about it: The world can be understood through careful, systematic study; scientific knowledge produced through such a process is both durable and subject to change; the scientific process cannot answer some questions, such as those about values and beliefs. In order to follow the science story as it unfolds, students need to understand these shared assumptions.

The map is organized around three strands—*limits of science, investigating a knowable world,* and *continuity and change*. In the elementary grades, the focus is on what can be learned from observation and experimentation. In middle school, ideas are introduced about the modifiability of science that results from new discoveries and about what cannot be studied in a scientific way. In high school, various historical episodes serve as examples of generalizations about continuity and change in science and the assumptions underlying a scientific world view.

Several historical episodes mapped in Chapter 10: HISTORICAL PERSPECTIVES illustrate how scientific knowledge is judged, modified, and replaced and exemplify major shifts in the scientific view of how the world works. The **CLASSICAL MECHANICS** map illustrates scientists' assumptions about the unity and understandability of the natural world.

NOTES

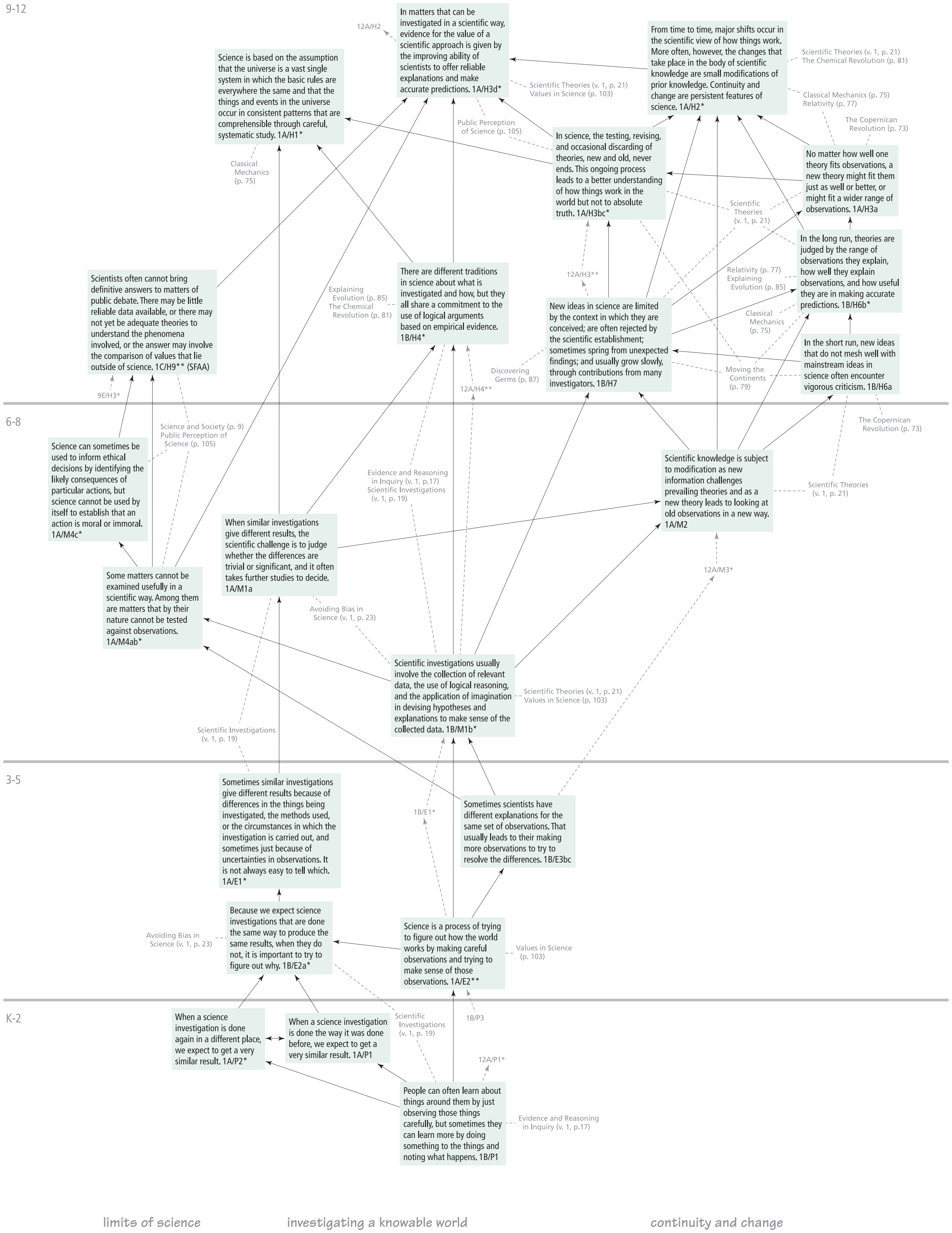
The 9-12 benchmark "Science is based on…" in the *investigating a knowable world* strand focuses on two related but separate premises. One is that by careful systematic study, people can figure out how the world works. The other is that the universe is a unified system and knowledge gained from studying one part of it can be applied to other parts.

The left-hand side of the strand includes ideas about the unity of nature. Nearly all of these benchmarks also appear in the **SCIENTIFIC INVESTIGATIONS** map in *Atlas 1* where they are part of a sequence of ideas about the importance of reliability in investigations. The right-hand side of the strand unpacks what is meant by careful systematic study of the world. In the grades 3-5 range, a new benchmark (1A/E2) describes what science is and its purpose at a level of complexity that most early elementary students can understand.

Benchmarks in the *continuity and change* strand also play a role in the *theory modification* strand in the **SCIENTIFIC THEORIES** map in *Atlas 1*.

RESEARCH IN *BENCHMARKS*

Although most students believe that scientific knowledge changes, they typically think changes occur mainly in facts and mostly through the invention of improved technology for observation and measurement. They do not recognize that changed theories sometimes suggest new observations or reinterpretation of previous observations (Aikenhead, 1987; Lederman & O'Malley, 1990; Waterman, 1983). Some research indicates that it is difficult for middle-school students to understand the development of scientific knowledge through the interaction of theory and observation (Carey et al., 1989), but the lack of long-term teaching interventions to investigate this issue makes it difficult to conclude that students can or cannot gain that understanding at this grade level.



Science is based on the assumption that the universe is a vast single system in which the basic rules are everywhere the same and that the things and events in the universe occur in consistent patterns that are comprehensible through careful, systematic study. 1A/H1*

In matters that can be investigated in a scientific way, evidence for the value of a scientific approach is given by the improving ability of scientists to offer reliable explanations and make accurate predictions. 1A/H3d*

From time to time, major shifts occur in the scientific view of how things work. More often, however, the changes that take place in the body of scientific knowledge are small modifications of prior knowledge. Continuity and change are persistent features of science. 1A/H2*

In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to a better understanding of how things work in the world but not to absolute truth. 1A/H3bc*

No matter how well one theory fits observations, a new theory might fit them just as well or better, or might fit a wider range of observations. 1A/H3a

In the long run, theories are judged by the range of observations they explain, how well they explain observations, and how useful they are in making accurate predictions. 1B/H6b*

Scientists often cannot bring definitive answers to matters of public debate. There may be little reliable data available, or there may not yet be adequate theories to understand the phenomena involved, or the answer may involve the comparison of values that lie outside of science. 1C/H9** (SFAA)

There are different traditions in science about what is investigated and how, but they all share a commitment to the use of logical arguments based on empirical evidence. 1B/H4*

New ideas in science are limited by the context in which they are conceived; are often rejected by the scientific establishment; sometimes spring from unexpected findings; and usually grow slowly, through contributions from many investigators. 1B/H7

In the short run, new ideas that do not mesh well with mainstream ideas in science often encounter vigorous criticism. 1B/H6a

Science can sometimes be used to inform ethical decisions by identifying the likely consequences of particular actions, but science cannot be used by itself to establish that an action is moral or immoral. 1A/M4c*

Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory leads to looking at old observations in a new way. 1A/M2

When similar investigations give different results, the scientific challenge is to judge whether the differences are trivial or significant, and it often takes further studies to decide. 1A/M1a

Some matters cannot be examined usefully in a scientific way. Among them are matters that by their nature cannot be tested against observations. 1A/M4ab*

Scientific investigations usually involve the collection of relevant data, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected data. 1B/M1b*

Sometimes similar investigations give different results because of differences in the things being investigated, the methods used, or the circumstances in which the investigation is carried out, and sometimes just because of uncertainties in observations. It is not always easy to tell which. 1A/E1*

Sometimes scientists have different explanations for the same set of observations. That usually leads to their making more observations to try to resolve the differences. 1B/E3bc

Because we expect science investigations that are done the same way to produce the same results, when they do not, it is important to try to figure out why. 1B/E2a*

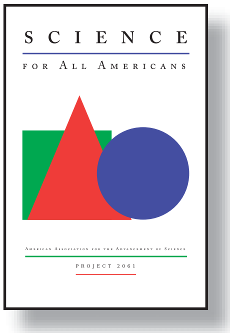
Science is a process of trying to figure out how the world works by making careful observations and trying to make sense of those observations. 1A/E2**

When a science investigation is done again in a different place, we expect to get a very similar result. 1A/P2*

When a science investigation is done the way it was done before, we expect to get a very similar result. 1A/P1

People can often learn about things around them by just observing those things carefully, but sometimes they can learn more by doing something to the things and noting what happens. 1B/P1

From *Science for All Americans,*
Chapter 1: The Nature of Science



SCIENCE
FOR ALL AMERICANS
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE
PROJECT 2061

The Scientific Enterprise

Science as an enterprise has individual, social, and institutional dimensions. Scientific activity is one of the main features of the contemporary world and, perhaps more than any other, distinguishes our times from earlier centuries.

Science Is a Complex Social Activity

Scientific work involves many individuals doing many different kinds of work and goes on to some degree in all nations of the world. Men and women of all ethnic and national backgrounds participate in science and its applications. These people—scientists and engineers, mathematicians, physicians, technicians, computer programmers, librarians, and others—may focus on scientific knowledge either for its own sake or for a particular practical purpose, and they may be concerned with data gathering, theory building, instrument building, or communicating.

As a social activity, science inevitably reflects social values and viewpoints. The history of economic theory, for example, has paralleled the development of ideas of social justice—at one time, economists considered the optimum wage for workers to be no more than what would just barely allow the workers to survive. Before the twentieth century, and well into it, women and people of color were essentially excluded from most of science by restrictions on their education and employment opportunities; the remarkable few who overcame those obstacles were even then likely to have their work belittled by the science establishment.

The direction of scientific research is affected by informal influences within the culture of science itself, such as prevailing opinion on what questions are most interesting or what methods of investigation are most likely to be fruitful. Elaborate processes involving scientists themselves have been developed to decide which research proposals receive funding, and committees of scientists regularly review progress in various disciplines to recommend general priorities for funding.

Science goes on in many different settings. Scientists are employed by universities, hospitals, business and industry, government, independent research organizations, and scientific associations. They may work alone, in small groups, or as members of large research teams. Their places of work include classrooms, offices, laboratories, and natural field settings from space to the bottom of the sea.

Because of the social nature of science, the dissemination of scientific information is crucial to its progress. Some scientists present their findings and theories in papers that are delivered at meetings or published in scientific journals. Those papers enable scientists to inform others about their work, to expose their ideas to criticism by other scientists, and, of course, to stay abreast of scientific developments around the world. The advancement of information science (knowledge of the nature of information and its manipulation) and the development of information technologies (especially computer systems) affect all sciences. Those technologies speed up data collection, compilation, and analysis; make new kinds of analysis practical; and shorten the time between discovery and application.

Science Is Organized Into Content Disciplines and Is Conducted in Various Institutions

Organizationally, science can be thought of as the collection of all of the different scientific fields, or content disciplines. From anthropology through zoology, there are dozens of such disciplines. They differ from one another in many ways, including history, phenomena studied, techniques and language used, and kinds of outcomes desired. With respect to purpose and philosophy, however, all are equally scientific and together make up the same scientific endeavor. The advantage of having disciplines is that they provide a conceptual structure for organizing research and research findings. The disadvantage is that their divisions do not necessarily match the way the world works, and they can make communication difficult. In any case, scientific disciplines do not have fixed borders. Physics shades into chemistry, astronomy, and geology, as does chemistry into biology and psychology, and so on. New scientific disciplines (astrophysics and sociobiology, for instance) are continually being formed at the boundaries of others. Some disciplines grow and break into subdisciplines, which then become disciplines in their own right.

Universities, industry, and government are also part of the structure of the scientific endeavor. University research usually emphasizes knowledge for its own sake, although much of it is also directed toward practical problems. Universities, of course, are also particularly committed to educating successive generations of scientists, mathematicians, and engineers. Industries and businesses usually emphasize research directed to practical ends, but many also sponsor research that has no immediately obvious applications, partly on the premise that it will be applied fruitfully in the long run. The federal government funds much of the research in universities and in industry but also supports and conducts research in its many national laboratories and research centers. Private foundations, public-interest groups, and state governments also support research.

Funding agencies influence the direction of science by virtue of the decisions they make on which research to support. Other deliberate controls on science result from federal (and sometimes local) government regulations on research practices that are deemed to be dangerous and on the treatment of the human and animal subjects used in experiments.

There Are Generally Accepted Ethical Principles in the Conduct of Science

Most scientists conduct themselves according to the ethical norms of science. The strongly held traditions of accurate recordkeeping, openness, and replication, buttressed by the critical review of one's work by peers, serve to keep the vast majority of scientists well within the bounds of ethical professional behavior. Sometimes, however, the pressure to get credit for being the first to publish an idea or observation leads some scientists to withhold information or even to falsify their findings. Such a violation of the very nature of science impedes science. When discovered, it is strongly condemned by the scientific community and the agencies that fund research.

Another domain of scientific ethics relates to possible harm that could result from scientific experiments. One aspect is the treatment of live experimental subjects. Modern scientific ethics require that due regard must be given to the health, comfort, and well-being of animal subjects. Moreover, research involving human subjects may be conducted only with the informed consent of the subjects, even if this constraint limits some kinds of potentially important research or influences the results. Informed consent entails full disclosure of the risks and intended benefits of the research and the right to refuse to participate. In addition, scientists must not knowingly subject coworkers, students, the neighborhood, or the community to health or property risks without their knowledge and consent.

The ethics of science also relates to the possible harmful effects of applying the results of research. The long-term effects of science may be unpredictable, but some idea of what applications are expected from scientific work can be ascertained by knowing who is interested in funding it. If, for example, the Department of Defense offers contracts for working on a line of theoretical mathematics, mathematicians may infer that it has application to new military technology and therefore would likely be subject to secrecy measures. Military or industrial secrecy is acceptable to some scientists but not to others. Whether a scientist chooses to work on research of great potential risk to humanity, such as nuclear weapons or germ warfare, is considered by many scientists to be a matter of personal ethics, not one of professional ethics.

Scientists Participate in Public Affairs Both as Specialists and as Citizens

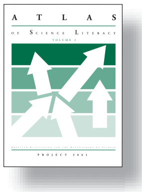
Scientists can bring information, insights, and analytical skills to bear on matters of public concern. Often they can help the public and its representatives to understand the likely causes of events (such as natural and technological disasters) and to estimate the possible effects of projected policies (such as ecological effects of various farming methods). Often they can testify to what is not possible. In playing this advisory role, scientists are expected to be especially careful in trying to distinguish fact from interpretation, and research findings from speculation and opinion; that is, they are expected to make full use of the principles of scientific inquiry.

Even so, scientists can seldom bring definitive answers to matters of public debate. Some issues are too complex to fit within the current scope of science, or there may be little reliable information available, or the values involved may lie outside of science. Moreover, although there may be at any one time a broad consensus on the bulk of scientific knowledge, the agreement does not extend to all scientific issues, let alone to all science-related social issues. And of course, on issues outside of their expertise, the opinions of scientists should enjoy no special credibility.

In their work, scientists go to great lengths to avoid bias—their own as well as that of others. But in matters of public interest, scientists, like other people, can be expected to be biased where their own personal, corporate, institutional, or community interests are at stake. For example, because of their commitment to science, many scientists may understandably be less than objective in their beliefs on how science is to be funded in comparison to other social needs.

THE NATURE OF SCIENCE

SCIENCE AND SOCIETY (1C)



Science both affects and is affected by society. Scientists influence social decision-making; new ideas in science challenge our views of the world, and new applications extend our abilities to shape it. At the same time, social and economic forces influence what research will be undertaken, paid attention to, and applied. Ethical principles inform the conduct of science and serve to keep the vast majority of scientists well within the bounds of ethical professional behavior.

The map is organized around three strands—*ethics in research, society affects science,* and *science affects society.* There are only a few benchmarks before the 6-8 grade range, in part because students need a clear idea of what science is as an intellectual endeavor before they can begin exploring how it affects and is affected by society.

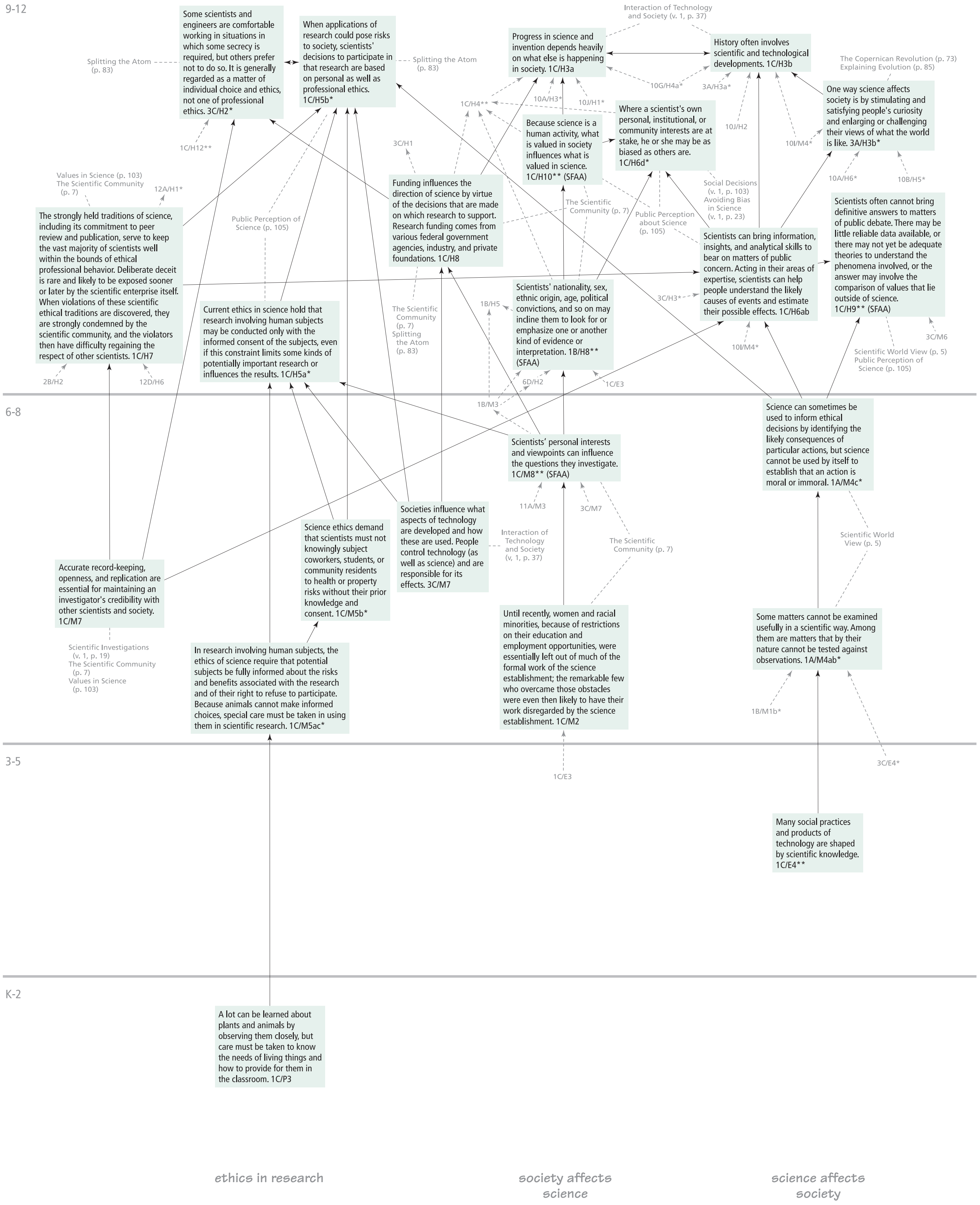
Related maps on **EVIDENCE AND REASONING IN INQUIRY** in *Atlas 1* and **DETECTING FLAWS IN ARGUMENTS** describe the principles of scientific inquiry and reasoning that can help students understand the role that scientists play in public affairs. Real-world examples of how science and society interact are presented in many of the Chapter 10 maps, which outline important episodes in the history of science, such as **SPLITTING THE ATOM, DISCOVERING GERMS**, and **THE INDUSTRIAL REVOLUTION**. Examples that involve technology are explored in the **TECHNOLOGY AND SCIENCE** map in this volume and the **INTERACTION OF TECHNOLOGY AND SOCIETY** map in *Atlas 1*.

NOTES

Three new 9-12 benchmarks in the *society affects science* strand relate to the idea that scientists are members of society and science and bring their own cultural backgrounds and views to both realms. The benchmarks have been added to clarify further the social nature of science ("Scientists' nationality, sex, ethnic origin…" and "Because science is a human activity…") and the limits of scientific expertise in resolving public issues ("Scientists often cannot bring definitive answers…"). Connections between benchmarks in the *science affects society* strand and the *ethics in research* strand center on the need for scientists to maintain credibility within society.

RESEARCH IN *BENCHMARKS*

Some students of all ages believe science mainly invents things or solves practical problems rather than exploring and understanding the world. Some high-school students believe that moral values and personal motives do not influence a scientist's contributions to the public debate about science and technology and think that scientists are more capable than others to decide those issues (Aikenhead, 1987; Fleming 1986a, 1986b, 1987).



9-12

Some scientists and engineers are comfortable working in situations in which some secrecy is required, but others prefer not to do so. It is generally regarded as a matter of individual choice and ethics, not one of professional ethics. 3C/H2*

When applications of research could pose risks to society, scientists' decisions to participate in that research are based on personal as well as professional ethics. 1C/H5b*

Progress in science and invention depends heavily on what else is happening in society. 1C/H3a

History often involves scientific and technological developments. 1C/H3b

Because science is a human activity, what is valued in society influences what is valued in science. 1C/H10** (SFAA)

Where a scientist's own personal, institutional, or community interests are at stake, he or she may be as biased as others are. 1C/H6d*

One way science affects society is by stimulating and satisfying people's curiosity and enlarging or challenging their views of what the world is like. 3A/H3b*

The strongly held traditions of science, including its commitment to peer review and publication, serve to keep the vast majority of scientists well within the bounds of ethical professional behavior. Deliberate deceit is rare and likely to be exposed sooner or later by the scientific enterprise itself. When violations of these scientific ethical traditions are discovered, they are strongly condemned by the scientific community, and the violators then have difficulty regaining the respect of other scientists. 1C/H7

Funding influences the direction of science by virtue of the decisions that are made on which research to support. Research funding comes from various federal government agencies, industry, and private foundations. 1C/H8

Scientists often cannot bring definitive answers to matters of public debate. There may be little reliable data available, or there may not yet be adequate theories to understand the phenomena involved, or the answer may involve the comparison of values that lie outside of science. 1C/H9** (SFAA)

Scientists can bring information, insights, and analytical skills to bear on matters of public concern. Acting in their areas of expertise, scientists can help people understand the likely causes of events and estimate their possible effects. 1C/H6ab

Current ethics in science hold that research involving human subjects may be conducted only with the informed consent of the subjects, even if this constraint limits some kinds of potentially important research or influences the results. 1C/H5a*

Scientists' nationality, sex, ethnic origin, age, political convictions, and so on may incline them to look for or emphasize one or another kind of evidence or interpretation. 1B/H8** (SFAA)

6-8

Scientists' personal interests and viewpoints can influence the questions they investigate. 1C/M8** (SFAA)

Science can sometimes be used to inform ethical decisions by identifying the likely consequences of particular actions, but science cannot be used by itself to establish that an action is moral or immoral. 1A/M4c*

Societies influence what aspects of technology are developed and how these are used. People control technology (as well as science) and are responsible for its effects. 3C/M7

Science ethics demand that scientists must not knowingly subject coworkers, students, or community residents to health or property risks without their prior knowledge and consent. 1C/M5b*

Accurate record-keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society. 1C/M7

Until recently, women and racial minorities, because of restrictions on their education and employment opportunities, were essentially left out of much of the formal work of the science establishment; the remarkable few who overcame those obstacles were even then likely to have their work disregarded by the science establishment. 1C/M2

Some matters cannot be examined usefully in a scientific way. Among them are matters that by their nature cannot be tested against observations. 1A/M4ab*

In research involving human subjects, the ethics of science require that potential subjects be fully informed about the risks and benefits associated with the research and of their right to refuse to participate. Because animals cannot make informed choices, special care must be taken in using them in scientific research. 1C/M5ac*

3-5

Many social practices and products of technology are shaped by scientific knowledge. 1C/E4**

K-2

A lot can be learned about plants and animals by observing them closely, but care must be taken to know the needs of living things and how to provide for them in the classroom. 1C/P3

ethics in research

society affects science

science affects society

Recommended Reading

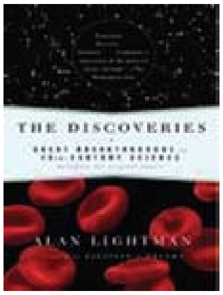
There are many well-written and authoritative books for a general audience that can help educators and others understand the nature of science and its role in society. For each of the examples below, we have identified the most significant links between the book's content and specific chapters and sections in *Science for All Americans (SFAA)*. Additional highly recommended trade books on topics covered in *Science for All Americans* can be found in *Resources for Science Literacy* online at **http://www.project2061.org/publications/rsl/online/index.htm**. For critical reviews of science books for readers of all ages, visit *Science Books & Films* online at **http://www.sbfonline.com/index.htm**.

SFAA link: 1B

The Discoveries: Great Breakthroughs in 20th-Century Science, Including the Original Papers

by Alan Lightman

(Illus.), NY Pantheon Books, 2005, 592pp., $32.50, 0-375-42168-8



Alan Lightman has an outstanding record as a physicist, novelist, popular science writer, essayist, and educator. He is currently an adjunct professor of humanities at MIT. Several years ago, he became interested in the intellectual and emotional background behind the great scientific discoveries of the 20th century. In this volume, he has reproduced 25 landmark papers by 23 famous scientists that he feels have changed our understanding of the world and our place in it. He uses all of his skills to bring us a book that will become a classic in the repertoire of readings on 20th-century history of science. The papers cover discoveries in physics, astronomy, chemistry, life science, and medicine and are by such scientists as Einstein, Hubble, Pauling, Watson, and Fleming. As an introduction to each paper, Lightman describes the historical background of the problem, the background of the author, and the author's introduction to the subject. He then describes, in the author's own words, when possible, the scientist's approach to the problem and the author's insight into the solution. This is followed by Lightman's almost line-per-line analysis of the paper in language an informed reader can well understand. He then closes with an evaluation on how the work in question has affected the works of other scientists and the author, as well as our views of the world. This is an excellent work! I look forward to other volumes that take its approach.

—*Reviewed by Robert J. Havlik, emeritus, University of Notre Dame, South Bend, IN*

CONTENTS

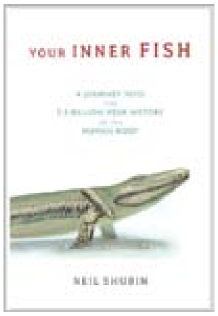
The Quantum • Antibiotics • Hormones • The Means of Production of Energy in Living Organisms • The Particle Nature of Light • Special Relativity • Nuclear Fission • The Nucleus of the Atom • The Movability of Genes • The Size of the Cosmos • The Structure of DNA • The Arrangement of Atoms • The Structure of Proteins in Solid Matter • Radio Waves from the Big Bang • The Quantum Atom • A Unified Theory of Forces • The Means of Communication between Nerves • Quarks: A Tiniest Essence of Matter • The Uncertainty Principle • The Creation of Altered Forms of Life • The Chemical Bond • The Expansion of the Universe • Epilogue

SFAA link: 1B, 5F

Your Inner Fish: A Journey into the 3.5 Billion-Year History of the Human Body

by Neil Shubin

(Illus.), NY Random House, 2008. ix+237pp., $13.95. 978-0-307-27745-9. Index



This is a terrifically informative and entertaining book. The author is Neil Shubin, codiscoverer of Tiktaalik: the 375 million-year-old intermediate between fish and the earliest land-living animals. Shubin combines discoveries from paleontology, developmental genetics, comparative anatomy, and comparative embryology to illustrate the wealth and breadth of evidence attesting to the shared common ancestry of all animals with a body plan. The evidence includes various "imperfections" and their historical legacies in our own bodies. There is even a terrific discussion of the 3,000 odor-detecting genes mammals possess (in cetaceans, they are all inactive) as examples of gene duplication. Few other books dealing with the evidence for human ancestry have done it in such an engaging way for the student and general reader. Most of the significance of Shubin's succinct descriptions of comparative anatomy is contained in the last chapter, titled "The Meaning of It All." Building on the biological "law of everything" (which asserts that every organism has parents) and its consequence (that organisms are modified descendants of their parents), Shubin proceeds to make a powerfully simple case for the biological evolution of all living species. He does this with an unexpected twist: Like Darwin in 1859, Shubin never uses the word "evolution" in this chapter or, indeed, anywhere else in the book! But, worry not: This entire book is an explicit argument for the continuity of life over geological time and the relatedness of all living animals. Shubin has written one of the most engaging and persuasive cases for evolution I have ever read.

—Reviewed by Martin K. Nickels, Illinois State University, Normal, IL

CONTENTS

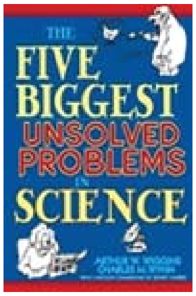
Finding Your Inner Fish • Adventures in Bodybuilding • Getting a Grip • Making Scents • Handy Genes • Vision • Teeth Everywhere • Ears • Getting Ahead • The Meaning of It All • The Best-Laid (Body) Plans • Epilogue

SFAA link: 1A, 1B

Five Biggest Unsolved Problems in Science

by Arthur Wiggins

(Illus.), NY Wiley, 2003, 234pp., $14.95, 0471268089, Index



To "the five biggest unsolved problems" in science, the writers bring the experience they gained writing about "the five biggest ideas" in science. The catchy title suggests marketing mastery, but the presentation of science is more masterful still. The problems discussed in this volume are the dueling concepts of mass and masslessness (physics), the passage from chemicals to living matter (chemistry), the complete structure of the proteome (biology), long-range weather forecasting (geology), and the expansion of the universe (astronomy). Lincoln once apologized for not taking time to be brief; when it comes to economy, these authors are masters. They know how to defer a topic while propelling a narrative. Many readers will be grateful to get from chapters of 25-35 intelligently illustrated pages the essence of what elsewhere fills volumes. The authors have managed to unify the set of problems with telling cross-references in the discussion of one problem to common physical principles invoked in discussions of the other four problems. All the while, the authors spare the reader mathematical challenges, writing at the level of readers who took a science course or two in college, but haven't kept current. Readers, once hooked by a problem, as many will be, can pursue related topics discussed, delve into further details, and survey some of the other materials that have been compiled and described in this volume.

—Reviewed by Blanchard E. Hiatt, Working Messages LLC, Scotch Plains, NJ

CONTENTS

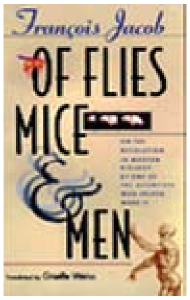
Science in Perspective • Physics: Why Do Some Particles Have Mass while Others Have None? • Chemistry: By What Series of Chemical Reactions Did Atoms Form the First Living Things? • Biology: What Is the Complete Structure and Function of the Proteome? • Geology: Is Accurate Long-range Weather Forecasting Possible? • Astronomy: Why Is the Universe Expanding Faster and Faster?

SFAA link: 1A, 1C

Of Flies, Mice, and Men

by François Jacob

(Illus.), Originally published in 1997, Cambridge, MA Harvard 1998, 158pp., $24.00, 0-674-63111-0, Index



This fascinating, easy-to-read book presents reflections and perspectives of a distinguished scientist on historical highlights in genetics and development. His philosophical perspectives provide the reader with profound insights into the nature of science. The section on "how a fly is built" is especially captivating. Jacob elaborates on the theme that "The fly became a sort of ideal model. Whatever progress we are able to make today in the genetic study of mice or humans, we owe to the fly." Personal anecdotes and brief stories from mythology enhance the reader's interest. From a personal perspective, the author discusses the advantages of doing research in pairs. He describes the thoughts and events that led to his difficult decision to perform further research on mice rather than bacteria. He provides valuable insights into the scientific process and emphasizes the gap between views of the scientist and perspectives of the public. He expresses his passion for the amazing phenomenon of development, which he sees as "so amazing that the whole world should marvel at it." Yet, he points out that, "aside from the rare expert, no one is interested in this extraordinary phenomenon." A thought-provoking explanation of biochemical evolution is offered, based upon the creation of new molecules and their subsequent selection and combinations. Jacob compares the living world to a giant Erector(tm) set: The same basic pieces in all organisms are combined in different ways to produce different forms. He elaborates upon this theme of the commonality of basic elements in all organisms, using the homeotic (Hom) genes and the presence of the master gene that integrates eye development in different organisms: "We are at once close relatives and are all different." Social, political, and moral implications of scientific developments are discussed in the context of the history of the eugenics movement. Jacob maintains that the role of the scientist is to present the whole truth to society; then citizens have to decide how this truth should be used. He compares art and science and urges that "in art as well as in science, what is important is to try all ideas." He argues that an outrageous experiment can open a new avenue of research and maintains that the beginning of research is always a leap into the unknown, and nobody can predict where the research will lead. This is an inspiring volume that causes the reader to reflect on the nature of science and its human implications. Everyone who has an interest in science should read the book.

—Reviewed by Marvin Druger, Syracuse University, Syracuse, NY

CONTENTS

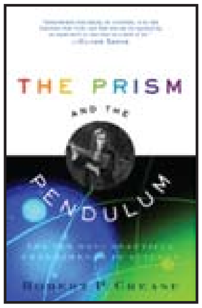
The Importance of the Unpredictable • The Fly • The Mouse • The Erector Set • Self and Other • Good and Evil • Beauty and Truth • Conclusion

SFAA link: 1B, 1C

The Prism and the Pendulum: The Ten Most Beautiful Experiments in Science

by Robert Crease

Random House, 2003, 224pp., $25.95, 1-4000-6131-8, Index



This book deserves high acclaim. Like Lewis Thomas's Lives of a Cell, it is one of those rare works that is a good read for scientists and the general public alike. It is at once scholarly and engaging. The premise is set forth in the subtitle. One might at first be disarmed by the juxtaposition of the words "beautiful," "experiments," and "science," but by the end of the book one has gained a deepened understanding of each of these terms. The author, Robert P. Crease, spans the disciplines of science and humanities, being a historian, a professor of philosophy, and a columnist for Physics World. The problem of selecting the 10 most beautiful experiments was solved democratically by polling readers. In each case, the problem, the experiment, and the experimenter are clearly and interestingly described. Each is followed by an "interlude," or commentary, on how the experiment qualifies as most beautiful and how art and science both give meaning to the term "beauty."

—Reviewed by Gary A. Griess, University of Texas Health Sciences Center, San Antonio, TX

CONTENTS

Measuring the World: Eratosthenes' Measurement of the Earth's Circumference *Interlude: Why Science Is Beautiful* • Dropping the Ball: The Legend of the Leaning Tower *Interlude: Experiments and Demonstrations* • The Alpha Experiment: Galileo and the Inclined Plane *Interlude: The Newton-Beethoven Comparison* • Experimentum Crucis: Newton's Decomposition of Sunlight with Prisms *Interlude: Does Science Destroy Beauty?* • Weighing the World: Cavendish's Austere Experiment *Interlude: Integrating Science and Popular Culture* • Light a Wave: Young's Lucid Analogy *Interlude: Science and Metaphor* • Seeing the Earth Rotate: Foucault's Sublime Pendulum *Interlude: Science and the Sublime* • Seeing the Electron: Millikan's Oil-Drop Experiment *Interlude: Perception in Science* • Dawning Beauty: Rutherford's Discovery of the Atomic Nucleus *Interlude: Artistry in Science*

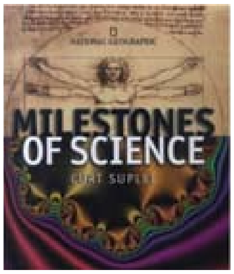
The Only Mystery: The Quantum Interference of Single Electrons *Interlude: Runners-Up* • Conclusion: Can Science Still Be Beautiful?

SFAA link: 1B, 1C, 3A

Milestones of Science

by Curt Suplee

(Illus.), National Geographic Society 2000, 288pp., $35.00, 0792279069, Index



One of the first questions a child may ask is "why?". The retention of such curiosity throughout life is one of the key elements in the growth of science and scientists. Many young people, however, soon loose interest in science when the going gets rough, and the spark of enthusiasm disappears. What is needed is an occasional graphic picture, such as this, of where science has been, where it is now, and where it is going. Curt Suplee, a science writer for the Washington Post, with the cooperation of the National Geographic Society, has written this very informative and vividly illustrated volume depicting the key figures and defining moments of scientific thought. The book uses a chronological approach. The first six chapters cover the spectrum of scientific achievement by eras labeled, "The Dawn of Inquiry", "The Classical Era", "The Middle Ages", "The Revolution", "The Age of Newton", and "The Age of Reason." Chapters on the 19th and 20th centuries, are each divided into two parts, "The Physical Sciences", and "The Life Sciences". His conclusion, "What the Future Holds" points out that: "Yet for every solution, there has been another puzzle; for every answer, another question." He concludes that, "... the 21' century will be as full of grand challenges to the mind as any that came before." Through such books more young people might be stimulated to continue a pursuit a fixture scientific career.

—Reviewed by Robert J. Havlik, emeritus, University of Notre Dame, South Bend, IN

CONTENTS

Introduction, The Dawn of inquiry • 600 B.C. to A.D. 500, The Classical era • A.D. 500 to 1500, The Middle ages • 1500 to 1650, The Revolution • 1650 to 1700, The Age of Newton

1700s, The Age of reason • 1800s Part One: The Physical sciences • 1800s Part Two: The Life sciences • 1900s Part One: The Physical sciences • 1900s Part Two: The Life sciences

From *Science for All Americans,*
Chapter 11: Common Themes

MODELS

A model of something is a simplified imitation of it that we hope can help us understand it better. A model may be a device, a plan, a drawing, an equation, a computer program, or even just a mental image. Whether models are physical, mathematical, or conceptual, their value lies in suggesting how things either do work or might work. For example, once the heart has been likened to a pump to explain what it does, the inference may be made that the engineering principles used in designing pumps could be helpful in understanding heart disease. When a model does not mimic the phenomenon well, the nature of the discrepancy is a clue to how the model can be improved. Models may also mislead, however, suggesting characteristics that are not really shared with what is being modeled. Fire was long taken as a model of energy transformation in the sun, for example, but nothing in the sun turned out to be burning.

Physical Models

The most familiar meaning of the term “model” is the physical model—an actual device or process that behaves enough like the phenomenon being modeled that we can hope to learn something from it. Typically, a physical model is easier to work with than what it represents because it is smaller in size, less expensive in terms of materials, or shorter in duration.

Experiments in which variables are closely controlled can be done on a physical model in the hope that its response will be like that of the full-scale phenomenon. For example, a scale model of an airplane can be used in a wind tunnel to investigate the effects of different wing shapes. Human biological processes can be modeled by using laboratory animals or cultures in test tubes to test medical treatments for possible use on people. Social processes too can be modeled, as when a new method of instruction is tried out in a single classroom rather than in a whole school system. But the scaling need not always be toward smaller and cheaper. Microscopic phenomena such as molecular configurations may require much larger models that can be measured and manipulated by hand.

A model can be scaled in time as well as in size and materials. Something may take so inconveniently long to occur that we observe only a segment of it. For example, we may want to know what people will remember years later of what they have been taught in a school course, but we settle for testing them only a week later. Short-run models may attempt to compress long-term effects by increasing the rates at which events occur. One example is genetic experimentation on organisms such as bacteria, flies, and mice that have large numbers of generations in a relatively short time span. Another important example is giving massive doses of chemicals to laboratory animals to try to get in a short time the effect that smaller doses would produce over a long time. A mechanical example is the destructive testing of products, using machines to simulate in hours the wear on, say, shoes or weapons that would occur over years in normal use. On the other hand, very rapid phenomena may require slowed-down models, such as slow-motion depiction of the motion of birds, dancers, or colliding cars.

The behavior of a physical model cannot be expected ever to represent the full-scale phenomenon with complete accuracy, not even in the limited set of characteristics being studied. If a model boat is very small, the way water flows past it will be significantly different from a real ocean and boat; if only one class in a school uses a new method, the specialness of it may make it more successful than the method would be if it were commonplace; large doses of a drug may have different kinds of effects (even killing instead of curing), not just quicker effects. The inappropriateness of a model may be related to such factors as changes in scale or the presence of qualitative differences that are not taken into account in the model (for example, rats may be sensitive to drugs that people are not, and vice versa).

Conceptual Models

One way to give an unfamiliar thing meaning is to liken it to some familiar thing—that is, to use metaphor or analogy. Thus, automobiles were first called horseless carriages. Living “cells” were so called because in plants they seemed to be lined up in rows like rooms in a monastery; an electric “current” was an analogy to a flow of water; the electrons in atoms were said to be arranged around the nucleus in “shells.” In each case, the metaphor or analogy is based on some attributes of similarity—but only some. Living cells do not have doors; electric currents are not wet; and electron shells do not have hard surfaces. So we can be misled, as well as assisted, by metaphor or analogy, depending on whether inappropriate aspects of likeness are inferred along with the appropriate aspects. For example, the metaphor for the repeated branching of species in the "tree of evolution" may incline one to think not just of branching but also of upward progress; the metaphor of a bush, on the other hand, suggests that the branching of evolution produces great diversity in all directions, without a preferred direction that constitutes progress. If some phenomenon is very unlike our ordinary experience, such as quantum phenomena on an atomic scale, there may be no single familiar thing to which we can liken it.

Like any model, a conceptual model may have only limited usefulness. On the one hand, it may be too simple. For example, it is useful to think of molecules of a gas as tiny elastic balls that are endlessly moving about, bouncing off one another; to accommodate other phenomena, however, such a model has to be greatly modified to include moving parts within each ball. On the other hand, a model may be too complex for practical use. The accuracy of models of complex systems such as global population, weather, and food distribution is limited by the large number of interacting variables that need to be dealt with simultaneously. Or, an abstract model may fit observations very well, but have no intuitive meaning. In modeling the behavior of molecules, for instance, we have to rely on a mathematical description that may not evoke any associated mental picture. Any model may have some irrelevant features that intrude on our use of it. For example, because of their high visibility and status, athletes and entertainers may be taken as role models by children not only in the aspects in which they excel but also in irrelevant—and perhaps distinctly less than ideal—aspects.

Mathematical Models

The basic idea of mathematical modeling is to find a mathematical relationship that behaves in the same way the system of interest does. (The system in this case can be other abstractions, as well as physical or biological phenomena.) For example, the increasing speed of a falling rock can be represented by the symbolic relation $v = gt$, where g has a fixed value. The model implies that the speed of fall (v) increases in proportion to the time of fall (t). A mathematical model makes it possible to predict what phenomena may be like in situations outside of those in which they have already been observed—but only what they may be like. Often, it is fairly easy to find a mathematical model that fits a phenomenon over a small range of conditions (such as temperature or time), but it may not fit well over a wider range. Although $v = gt$ does apply accurately to objects such as rocks falling (from rest) more than a few meters, it does not fit the phenomenon well if the object is a leaf (air drag limits its speed) or if the fall is a much larger distance (the drag increases, the force of gravity changes).

Mathematical models may include a set of rules and instructions that specifies precisely a series of steps to be taken, whether the steps are arithmetic, logical, or geometric. Sometimes even very simple rules and instructions can have consequences that are extremely difficult to predict without actually carrying out the steps. High-speed computers can explore what the consequences would be of carrying out very long or complicated instructions. For example, a nuclear power station can be designed to have detectors and alarms in all parts of the control system, but predicting what would happen under various complex circumstances can be very difficult. The mathematical models for all parts of the control system can be linked together to simulate how the system would operate under various conditions of failure.

What kind of model is most appropriate varies with the situation. If the underlying principles are poorly understood, or if the mathematics of known principles is very complicated, a physical model may be preferable; such has been the case, for example, with the turbulent flow of fluids. The increasing computational speed of computers makes mathematical modeling and the resulting graphic simulation suitable for more and more kinds of problems.

COMMON THEMES

MODELS (11B)

A model of something is a simplified imitation of it that we hope can help us understand it better. Scientists spend a good deal of time building, testing, comparing and revising models—whether mathematical, physical, or conceptual—and using them to communicate and get ideas about how the real world works. Tables used in determining insurance payments, projections about endangered species, non-destructive testing of bridges, and weather forecasting are all based on models. When a model does not mimic a phenomenon well, the nature of the discrepancy is a clue to how the model can be improved. Models may also mislead, suggesting characteristics that are not really shared with what is being modeled.

The map is organized around two strands—*uses of models* and *limitations of models*. In the elementary grades, the focus is on uses of a variety of models as communication devices and, when the things being modeled are readily observable, on how the models are like and unlike those things. In middle school, the focus is on models of phenomena not accessible through direct observation and on the role of various models, including simulations, in helping us think about phenomena. In high school, the focus is on what can and cannot be learned from models, including computer-based models.

Maps in Chapter 2: THE NATURE OF MATHEMATICS are closely related to the ideas on this map. In particular, the **MATHEMATICAL MODELS** map in *Atlas 1* addresses more extensively the processes of mathematical modeling that are touched on here.

NOTES

The K-2 benchmark "Many toys are like real things in some ways…" builds on a common understanding of models as three-dimensional miniatures of objects but notes similarities between toys and the real things in terms of what they do in addition to what they look like. New benchmarks at the grades 3-5 and 6-8 levels point out ways in which models may differ from what they represent and the need to consider whether a model's behavior matches key aspects of what is being modeled.

The high-school benchmark 11B/H3 includes two fairly sophisticated ideas: (a) a model can be tested by comparing its predictions to observations, and (b) a close match between predictions based on the model and observations does not mean that another model might not work equally well or better.

Numerous off-map connections highlight the importance of models to various aspects of science and engineering.

RESEARCH IN *BENCHMARKS*

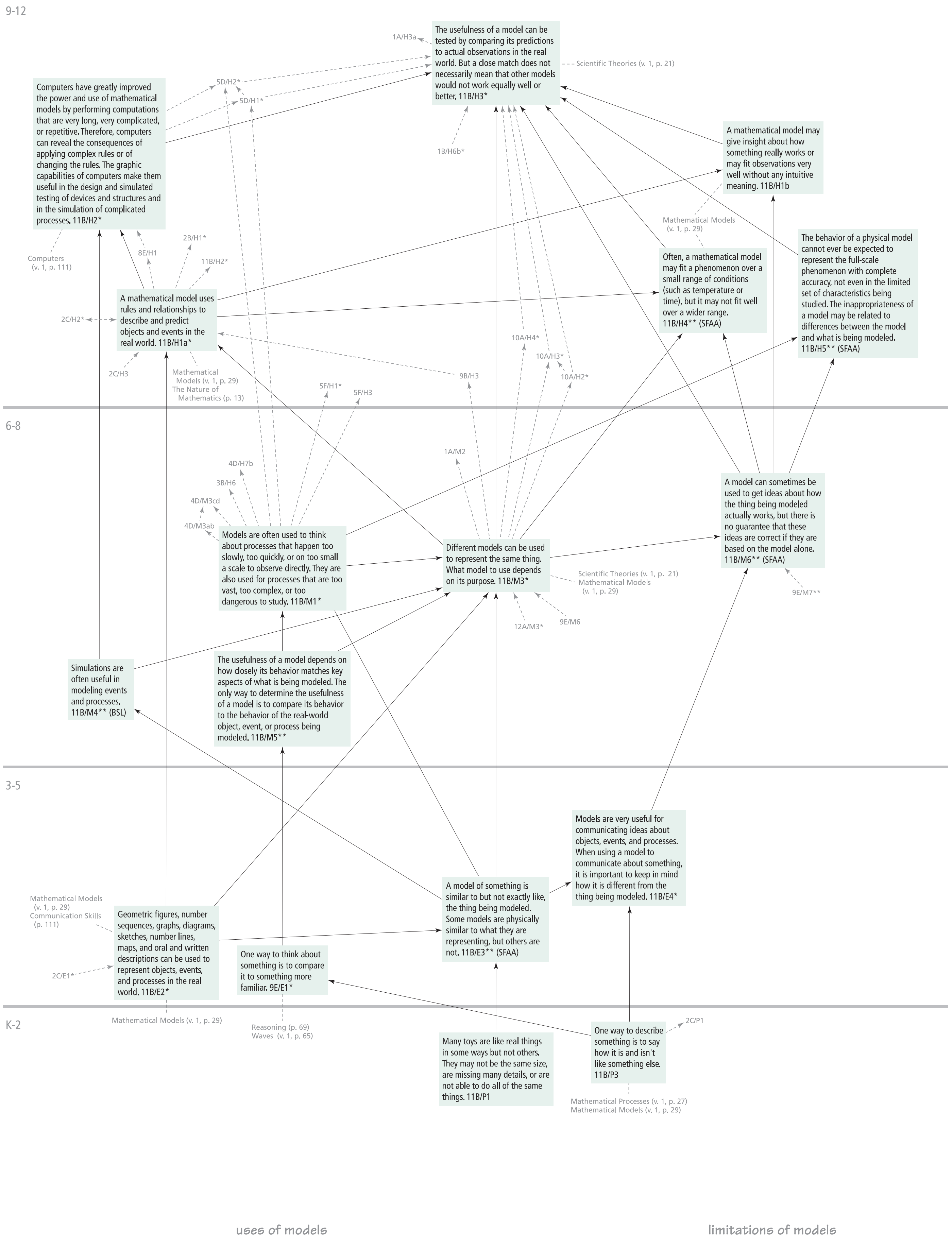
Students in lower elementary grades have some understanding that models can be used to show how something works, but they believe that perceptual similarity between the model and what it is used to represent is very important when developing or evaluating models (Penner, Giles, Lehrer, & Schauble, 1997). With repeated cycles of modeling and reflection, lower elementary students can focus more on similarities in function and less on perceptual similarities, and upper elementary students can understand the need for symbolic conventions (rather than only physical resemblance) when developing maps, diagrams, and other related display notations (Lehrer & Schauble, 2000).

Prior to instruction, or after traditional instruction, many middle- and high-school students continue to focus on perceptual rather than functional similarities between models and their referents, and think of models predominantly as small copies of real objects (Grosslight, Unger, Jay, & Smith, 1991; Treagust, Chittleborough, & Mamiala, 2002; Schwartz & White, 2005). Consequently, students often interpret models they encounter in school science too literally and unshared attributes between models and their referents are a cause of misunderstanding (Coll, France, & Taylor, 2005; Harrison & Treagust, 1996). Some middle- and high-school students view visual representations such as maps or diagrams as models, but only a few students view representations of ideas or abstract entities as models (Grosslight et al., 1991).

Many middle- and high-school students think that models are useful for visualizing ideas and for communication purposes (Schwarz & White, 2005; Grosslight et al., 1991). Only a few students think that models are useful in developing and testing ideas and that the usefulness of a model can be tested by comparing its implications to actual observations (Grosslight et al., 1991).

Middle-school and high-school students accept the idea that scientists can have more than one model for the same thing (Grosslight et al., 1991). However, having multiple models may mean for them that one could have literally a different view of the same entity, or that one could emphasize different aspects of the entity—omitting or highlighting certain things to provide greater clarity. Students are rarely aware that there could be different models to explain something or to evaluate alternative hypotheses. They find multiple model use in school science confusing and rarely use multiple models to think about phenomena; even if they do, the idea that one model is "right" and "real" persists (Harrison & Treagust, 1996, 2000). Students may know that models can be changed, but changing a model for them means (typical of high-school students) adding new information or (typical of middle-school students) replacing a part that was made wrong (Grosslight et al., 1991).

Developing and evaluating models *combined* with explicit instruction and reflection about the nature of models and modeling for an extended period of time can be effective in helping middle-school students make progress toward the following ideas: Models are not necessarily physical objects but could be conceptual representations that help scientists to predict and explain; there can be multiple models for the same phenomenon; and models are useful in visualization, predicting phenomena, and conducting investigations that are not otherwise possible (Schwarz & White, 2005). The ideas that scientists revise their models in light of new insights or new data and that not all models are of equal value may be harder to develop (Schwarz & White, 2005).



The usefulness of a model can be tested by comparing its predictions to actual observations in the real world. But a close match does not necessarily mean that other models would not work equally well or better. 11B/H3*

Computers have greatly improved the power and use of mathematical models by performing computations that are very long, very complicated, or repetitive. Therefore, computers can reveal the consequences of applying complex rules or of changing the rules. The graphic capabilities of computers make them useful in the design and simulated testing of devices and structures and in the simulation of complicated processes. 11B/H2*

A mathematical model may give insight about how something really works or may fit observations very well without any intuitive meaning. 11B/H1b

The behavior of a physical model cannot ever be expected to represent the full-scale phenomenon with complete accuracy, not even in the limited set of characteristics being studied. The inappropriateness of a model may be related to differences between the model and what is being modeled. 11B/H5** (SFAA)

Often, a mathematical model may fit a phenomenon over a small range of conditions (such as temperature or time), but it may not fit well over a wider range. 11B/H4** (SFAA)

A mathematical model uses rules and relationships to describe and predict objects and events in the real world. 11B/H1a*

Models are often used to think about processes that happen too slowly, too quickly, or on too small a scale to observe directly. They are also used for processes that are too vast, too complex, or too dangerous to study. 11B/M1*

Different models can be used to represent the same thing. What model to use depends on its purpose. 11B/M3*

A model can sometimes be used to get ideas about how the thing being modeled actually works, but there is no guarantee that these ideas are correct if they are based on the model alone. 11B/M6** (SFAA)

Simulations are often useful in modeling events and processes. 11B/M4** (BSL)

The usefulness of a model depends on how closely its behavior matches key aspects of what is being modeled. The only way to determine the usefulness of a model is to compare its behavior to the behavior of the real-world object, event, or process being modeled. 11B/M5**

Models are very useful for communicating ideas about objects, events, and processes. When using a model to communicate about something, it is important to keep in mind how it is different from the thing being modeled. 11B/E4*

A model of something is similar to but not exactly like, the thing being modeled. Some models are physically similar to what they are representing, but others are not. 11B/E3** (SFAA)

Geometric figures, number sequences, graphs, diagrams, sketches, number lines, maps, and oral and written descriptions can be used to represent objects, events, and processes in the real world. 11B/E2*

One way to think about something is to compare it to something more familiar. 9E/E1*

Many toys are like real things in some ways but not others. They may not be the same size, are missing many details, or are not able to do all of the same things. 11B/P1

One way to describe something is to say how it is and isn't like something else. 11B/P3

Finding Out What Students Know

About scientific inquiry...

The identification of causal links between seemingly related events is a major part of the work of science. Therefore, it is important for students to understand what is required to make claims of causality and to recognize when causal claims are being made with insufficient evidence to support those claims. To progress towards this understanding, middle school students are expected to understand several key ideas, including the following:

> If more than one variable changes at the same time in an experiment, the outcome of the experiment may not be clearly attributable to any one of the variables.

The item below was developed to determine if students understand that the way to determine if one variable is related to another is to hold all other relevant variables constant. The item was also designed to test a number of common misconceptions that students have regarding the control of variables, including the idea that all of the variables should be allowed to vary in a controlled experiment.

A track team captain thinks that eating breakfast and having a good night's sleep may affect the team's performance.

The track team decides to *test if eating breakfast makes a difference in how fast they can run one mile.* They decide to split the team into two groups. One group eats breakfast 2 hours before running, and the other group does not eat breakfast.

The students also make a rule that both groups have to get a good night's sleep the night before. Is this rule necessary?

A. *No,* because they can judge the effect of having breakfast even if the students do not get enough sleep.

B. *No,* because they can judge the effect of having breakfast only if some students do not get enough sleep.

C. *Yes,* because they can judge the effect of having breakfast only if all students get enough sleep.

D. *Yes,* because they can judge the effect of both breakfast and sleep if all students get enough sleep.

About the use of models...

Scientists spend a good deal of time building, testing, comparing, and revising models and using them to develop and communicate ideas about how the real world works. Tables used in determining insurance payments, projections about endangered species, non-destructive testing of bridges, and weather forecasting are all based on models. When a model does not mimic or predict a phenomenon well, the nature of the discrepancy is a clue to how the model can be improved. To progress towards this understanding, middle school students are expected to understand several key ideas, including the following:

> In thinking about objects, events, and processes, the usefulness of a model depends on how closely its behavior matches key aspects of what is being modeled.

The item below was developed to determine if students understand that the only way to judge the appropriateness of a model is to check to see if the real-world phenomenon behaves the way the model predicts it will behave. The item was also designed to test a number of common misconceptions that students have regarding models, including the idea that the most important criterion for judging the appropriateness of a model is how closely it physically resembles the real-world phenomenon it represents.

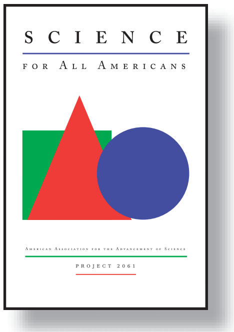
An engineer wants to know whether a new type of airplane will fly when it is raining. She makes a model of the airplane and finds out that the model is able to fly in the rain. What conclusions can she draw?

A. She can be absolutely certain that the real airplane will fly well in the rain because the model flew well when it was raining.

B. She can be absolutely certain that the real airplane will fly well in the rain, but only if her model includes all of the things she thinks might affect how the real airplane flies in the rain.

C. She cannot be absolutely certain that the real airplane will fly well in the rain unless she actually flies the real airplane in the rain.

D. She cannot be absolutely certain that the real airplane will fly well in the rain because predictions made using models are never accurate.



**From *Science for All Americans*,
Chapter 12: Habits of Mind**

Throughout history, people have concerned themselves with the transmission of shared values, attitudes, and skills from one generation to the next. All three were taught long before formal schooling was invented. Even today, it is evident that family, religion, peers, books, news and entertainment media, and general life experiences are the chief influences in shaping people's views of knowledge, learning, and other aspects of life. Science, mathematics, and technology—in the context of schooling—can also play a key role in the process, for they are built upon a distinctive set of values, they reflect and respond to the values of society generally, and they are increasingly influential in shaping shared cultural values. Thus, to the degree that schooling concerns itself with values and attitudes—a matter of great sensitivity in a society that prizes cultural diversity and individuality and is wary of ideology—it must take scientific values and attitudes into account when preparing young people for life beyond school.

Similarly, there are certain thinking skills associated with science, mathematics, and technology that young people need to develop during their school years. These are mostly, but not exclusively, mathematical and logical skills that are essential tools for both formal and informal learning and for a lifetime of participation in society as a whole.

Taken together, these values, attitudes, and skills can be thought of as habits of mind because they all relate directly to a person's outlook on knowledge and learning and ways of thinking and acting.

VALUES AND ATTITUDES

Science education should contribute to people's knowledge of the shared values of scientists, mathematicians, and engineers; reinforcement of general societal values; the inculcation in people of informed, balanced beliefs about the social value of science, mathematics, and technology; and the development in young people of positive attitudes toward learning science, mathematics, and technology.

CRITICAL-RESPONSE SKILLS

In various forms, the mass media, teachers, and peers inundate students with assertions and arguments, some of them in the realm of science, mathematics, and technology. Education should prepare people to read or listen to such assertions critically, deciding what evidence to pay attention to and what to dismiss, and distinguishing careful arguments from shoddy ones. Furthermore, people should be able to apply those same critical skills to their own observations, arguments, and conclusions, thereby becoming less bound by their own prejudices and rationalizations.

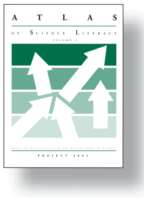
Although most people cannot be expected to become experts in technical fields, everyone can learn to detect the symptoms of doubtful assertions and arguments. These have to do with the ways in which purported results are reported.

COMMUNICATION SKILLS

Discourse in science, mathematics, and technology calls for the ability to communicate ideas and share information with fidelity and clarity, and to read and listen with understanding. Some of the skills involved are specific to science, mathematics, and technology, and others are general—although even those are not independent of content.

HABITS OF MIND

VALUES IN SCIENCE (12A)



To understand the enterprises of science, mathematics, and technology, it is essential to be aware of the values that underlie them and that are shared by the people who work in them: the importance of verifiable data, testable hypotheses, and predictability in science; of rigorous proof and elegance in mathematics; and of optimum design in technology.

Science is also based on everyday values even as it questions our understanding of the world and ourselves. In many respects, science is the systematic application of some highly regarded and widely held human values—integrity, diligence, fairness, curiosity, openness to new ideas, skepticism, and imagination.

The map is organized around two strands—*values particular to science* and *common values as applied in science*. In the elementary grades, the focus is on the importance of observations in making sense of phenomena. In middle school, the focus is on the importance of reproducible evidence and logical reasoning in drawing conclusions from data. In high school, the focus is on understanding why curiosity, honesty, openness, and skepticism are so highly regarded in science and how they are incorporated into the way science is carried out.

The map draws on and contributes to ideas on maps in Chapter 1: THE NATURE OF SCIENCE and to the **DETECTING FLAWS IN ARGUMENTS** map.

NOTES

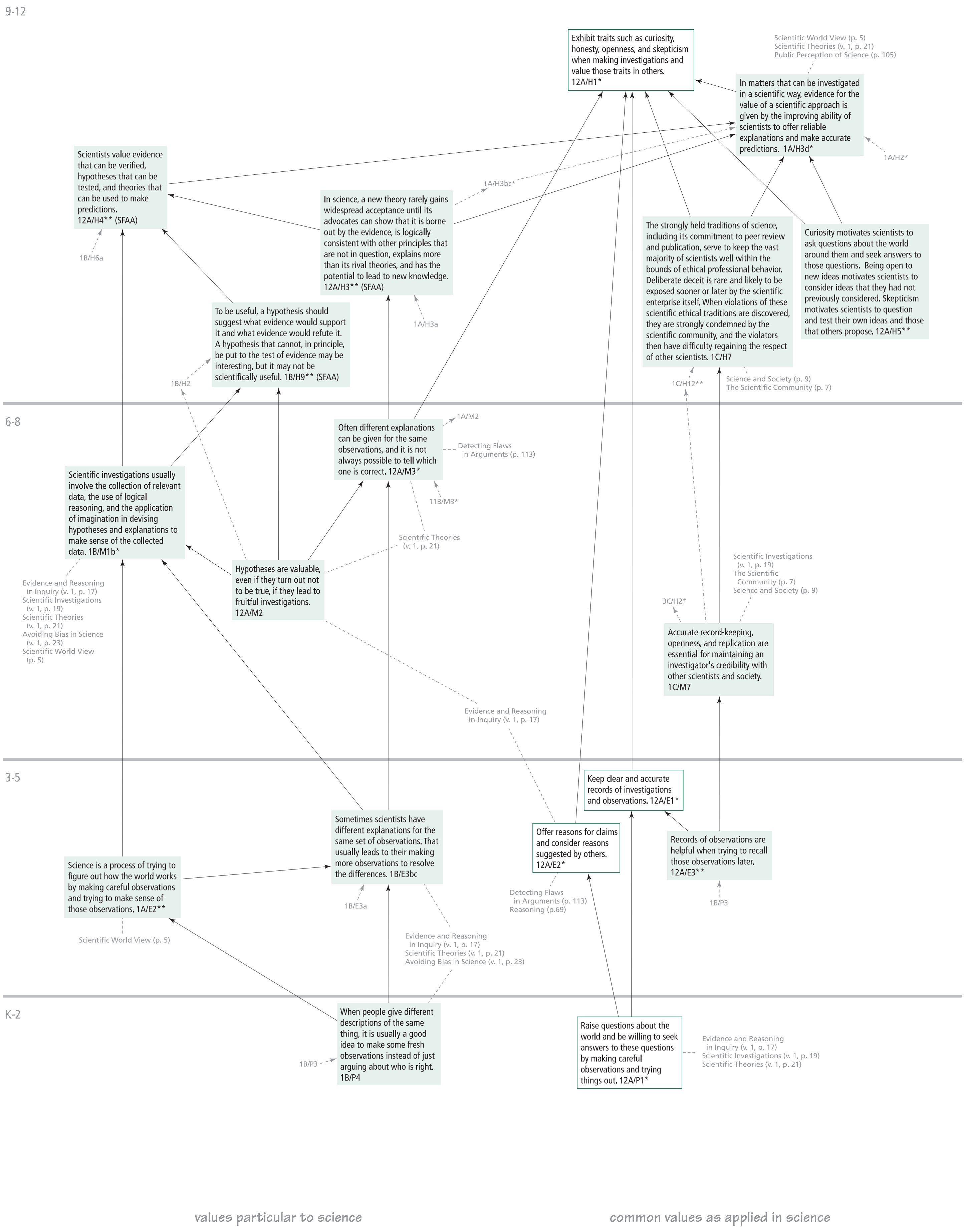
The *values particular to science* strand contains three benchmarks at the high-school level that have been developed using ideas found in *Science for All Americans*. Together, they describe the importance of hypotheses, evidence, and theories to the scientific endeavor. In grades 3-5, the new benchmark "Science is a process…" provides young students with an age-appropriate way to understand what science is.

In the *common values as applied in science* strand, two new benchmarks have been developed for the map. Benchmark 12A/E3 provides a reason for students to keep clear and accurate records as is called for in benchmark 12A/E1. At the high-school level, benchmark 12A/H5 provides a justification for students to acquire the traits of curiosity, openness, and skepticism as described in benchmark 12A/H1. Honesty is also called for in benchmark 12A/H1, and the justification for it is already captured in benchmark 1C/H7.

Several benchmarks on the map have been edited to improve their clarity and to better align the expectations on this map with the descriptions of goals in *Science for All Americans.*

RESEARCH IN *BENCHMARKS*

No relevant research available in *Benchmarks*.



9-12

Exhibit traits such as curiosity, honesty, openness, and skepticism when making investigations and value those traits in others. 12A/H1*

Scientific World View (p. 5)
Scientific Theories (v. 1, p. 21)
Public Perception of Science (p. 105)

In matters that can be investigated in a scientific way, evidence for the value of a scientific approach is given by the improving ability of scientists to offer reliable explanations and make accurate predictions. 1A/H3d*

1A/H2*

Scientists value evidence that can be verified, hypotheses that can be tested, and theories that can be used to make predictions. 12A/H4** (SFAA)

1B/H6a

1A/H3bc*

In science, a new theory rarely gains widespread acceptance until its advocates can show that it is borne out by the evidence, is logically consistent with other principles that are not in question, explains more than its rival theories, and has the potential to lead to new knowledge. 12A/H3** (SFAA)

1A/H3a

To be useful, a hypothesis should suggest what evidence would support it and what evidence would refute it. A hypothesis that cannot, in principle, be put to the test of evidence may be interesting, but it may not be scientifically useful. 1B/H9** (SFAA)

1B/H2

The strongly held traditions of science, including its commitment to peer review and publication, serve to keep the vast majority of scientists well within the bounds of ethical professional behavior. Deliberate deceit is rare and likely to be exposed sooner or later by the scientific enterprise itself. When violations of these scientific ethical traditions are discovered, they are strongly condemned by the scientific community, and the violators then have difficulty regaining the respect of other scientists. 1C/H7

Curiosity motivates scientists to ask questions about the world around them and seek answers to those questions. Being open to new ideas motivates scientists to consider ideas that they had not previously considered. Skepticism motivates scientists to question and test their own ideas and those that others propose. 12A/H5**

1C/H12**

Science and Society (p. 9)
The Scientific Community (p. 7)

6-8

Often different explanations can be given for the same observations, and it is not always possible to tell which one is correct. 12A/M3*

1A/M2

Detecting Flaws in Arguments (p. 113)

11B/M3*

Scientific investigations usually involve the collection of relevant data, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected data. 1B/M1b*

Scientific Theories (v. 1, p. 21)

Hypotheses are valuable, even if they turn out not to be true, if they lead to fruitful investigations. 12A/M2

Evidence and Reasoning in Inquiry (v. 1, p. 17)
Scientific Investigations (v. 1, p. 19)
Scientific Theories (v. 1, p. 21)
Avoiding Bias in Science (v. 1, p. 23)
Scientific World View (p. 5)

Scientific Investigations (v. 1, p. 19)
The Scientific Community (p. 7)
Science and Society (p. 9)

3C/H2*

Accurate record-keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society. 1C/M7

Evidence and Reasoning in Inquiry (v. 1, p. 17)

3-5

Keep clear and accurate records of investigations and observations. 12A/E1*

Sometimes scientists have different explanations for the same set of observations. That usually leads to their making more observations to resolve the differences. 1B/E3bc

Offer reasons for claims and consider reasons suggested by others. 12A/E2*

Records of observations are helpful when trying to recall those observations later. 12A/E3**

Science is a process of trying to figure out how the world works by making careful observations and trying to make sense of those observations. 1A/E2**

1B/E3a

Detecting Flaws in Arguments (p. 113)
Reasoning (p.69)

1B/P3

Scientific World View (p. 5)

Evidence and Reasoning in Inquiry (v. 1, p. 17)
Scientific Theories (v. 1, p. 21)
Avoiding Bias in Science (v. 1, p. 23)

K-2

When people give different descriptions of the same thing, it is usually a good idea to make some fresh observations instead of just arguing about who is right. 1B/P4

1B/P3

Raise questions about the world and be willing to seek answers to these questions by making careful observations and trying things out. 12A/P1*

Evidence and Reasoning in Inquiry (v. 1, p. 17)
Scientific Investigations (v. 1, p. 19)
Scientific Theories (v. 1, p. 21)

values particular to science

common values as applied in science

HABITS OF MIND

DETECTING FLAWS IN ARGUMENTS (12E)

In various forms, the mass media, authority figures, and peers inundate us with assertions and arguments, some of them in the realm of science, mathematics, and technology. Education should prepare people to read or listen to such assertions critically, deciding what evidence to pay attention to and what to dismiss, and distinguishing careful arguments from shoddy ones. Furthermore, people should be able to apply those same critical skills to their own observations, arguments, and conclusions, thereby becoming less bound by their own prejudices and rationalizations.

The map is organized around seven strands that reflect the ability to detect various sources of flawed arguments—*detecting bias, detecting misuse of numbers, detecting overgeneralization, detecting unfair comparisons, detecting flawed reasoning, detecting alternative explanations,* and *detecting unsupported claims*. The development of critical response skills starts with the inclination to seek evidence for claims and to question claims that are not based on fair comparisons. In middle school, the emphasis is on questioning claims and reasoning based on insufficient or flawed data. In high school, the emphasis is on detecting flaws in arguments based on faulty use of numbers and on omitting data, key assumptions, or alternative explanations from arguments.

The map draws on ideas about the importance of evidence and adequate controls on the **EVIDENCE AND REASONING IN INQUIRY** map in *Atlas 1* and on mathematical ideas on the **REASONING** map in this volume.

NOTES

There are a fairly large number of strands in this map to reflect the wide variety of skills that students need to think critically. Throughout the map, the wording of several benchmarks has been revised to improve its clarity.

Most of the benchmarks in grades K-8 contribute to the benchmark "Notice and criticize the reasoning in arguments in which the claims are not consistent with the evidence given." At the high-school level, benchmark 12E/H4 expects students to analyze their own and other people's arguments for faulty evidence and reasoning.

RESEARCH IN *BENCHMARKS*

Upper elementary-school students can reject a proposed experimental test where a factor whose effect is intuitively obvious is uncontrolled, at the level of "that's not fair" (Shayer & Adey, 1981). "Fairness" develops as an intuitive principle as early as 7 to 8 years of age and provides a sound basis for understanding experimental design. This intuition does not, however, develop spontaneously into a clear, generally applicable procedure for planning experiments (Wollman, 1977a, 1977b; Wollman & Lawson, 1977; Zimmerman, 2005). Although young children have a sense of what it means to run a fair test, they frequently cannot identify all the important variables, and they are more likely to control those variables that they believe will affect the result. In evaluating what can be learned from a certain experiment, students may be less likely to detect a problem in controlling variables when the outcome is expected than when the outcome is not expected (Wollman, 1977b). Student familiarity with the topic of the given experiment influences the likelihood that they will control variables (Linn & Swiney, 1981; Linn et al., 1983).

Students of all ages as well as adults may change variables one at a time to test a claim whose outcome may be construed as negative (e.g., honey makes a cake taste bad). But when the outcome is construed as positive (e.g., honey makes a cake taste good), they may hold constant what they believe is contributing to the positive outcome (Zimmerman, 2000, 2005).

After specially designed instruction, students in 8th grade are able to call attention to inadequate data resulting from lack of controls (see for example Rowell & Dawson, 1984; Ross, 1988). Explicit instruction that includes positive and negative examples of control-of-variables designs and justification for why the strategy works, combined with hands-on experimentation, can help upper elementary-school students make progress toward designing unconfounded experiments and evaluating experiments designed by others (Klahr, Chen, & Toth, 2001).

Lower elementary-school students can select conclusive (over inconclusive) tests for specific simple hypotheses (Sodian, Zaitchik, & Carey, 1991), and most 6th-graders can judge whether evidence is related to a theory, although they do not always evaluate this evidence correctly (Kuhn et al., 1988). When asked to use evidence to judge a theory, however, students of all ages may make only theory-based responses with no reference made to the presented evidence. Sometimes this appears to be because the available evidence conflicts with the students' beliefs (Kuhn et al., 1988). High-school students are more capable of evaluating theories in terms of their consistency with evidence, regardless of whether or not they believe the theory (Driver et al., 1996). This does not necessarily indicate that students appreciate the centrality of this kind of reasoning in science or that they will be inclined to evaluate claims in terms of consistency with evidence if they are not explicitly prompted (Driver et al., 1996).

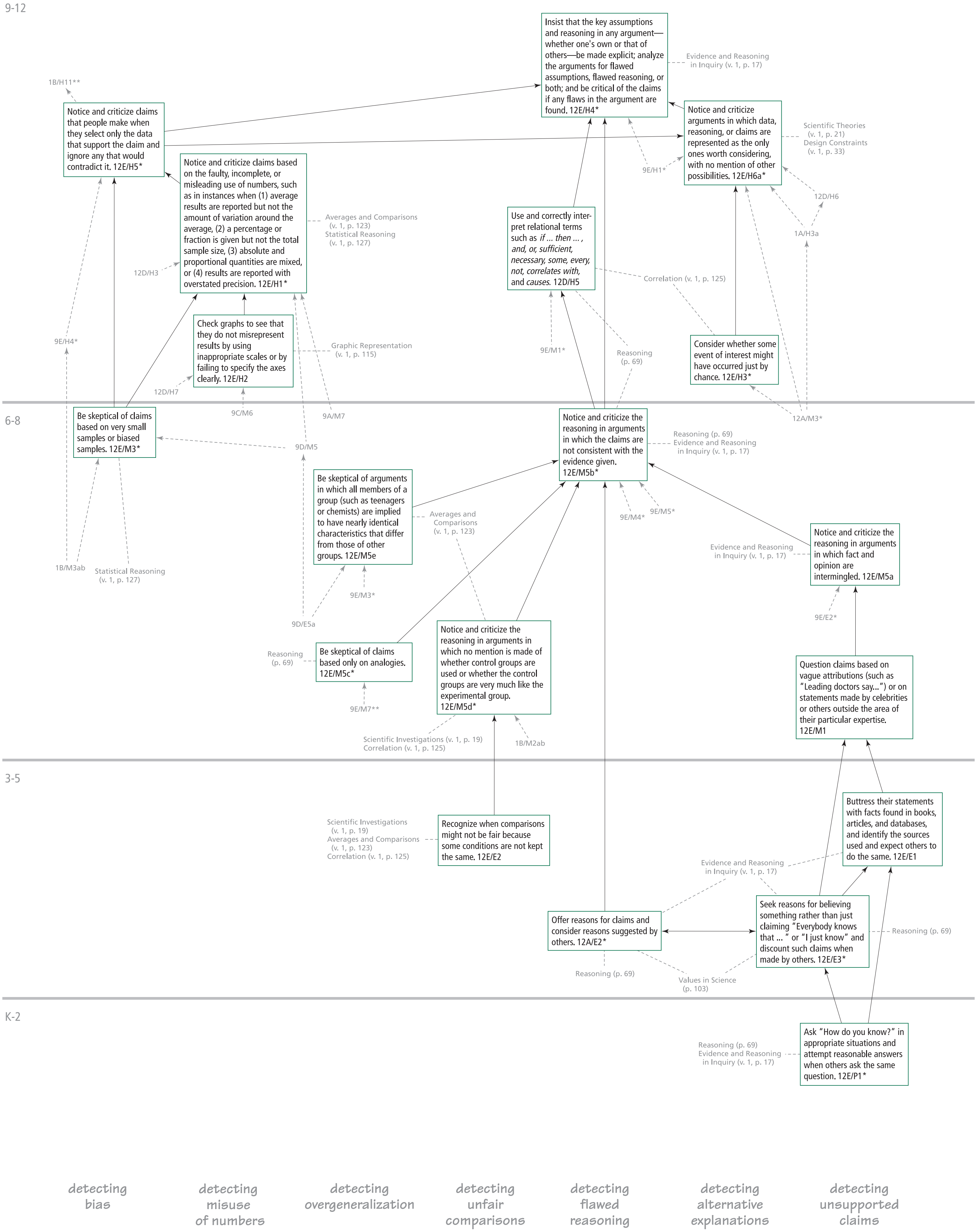
Students may cite data in their arguments, but they may fail to cite sufficient evidence for claims. In addition, references to data in students' arguments often fail to articulate how specific data relate to specific claims (Sandoval & Millwood, 2005). Students may believe that data literally speak for themselves—that they are self-evident—rather than providing raw material for supporting or judging a claim (Driver et al., 1996; Sandoval & Millwood, 2005).

Some middle-school students tend to invoke personal experiences as evidence to justify a particular hypothesis. Specifically, they seem to think of evidence as selected from what is already known or from personal experience or second-hand sources, not as information produced by experiment (Roseberry et al., 1992; Ratcliffe, 1999).

Students do not necessarily consider only the evidence that is presented to them but make additional assertions about the context of the problem, or even introduce inferences that go beyond the boundaries of the evidence presented and that introduce bias in the outcome (Driver et al., 2000).

See **REASONING** for additional research.

DETECTING FLAWS IN ARGUMENTS



9-12

Insist that the key assumptions and reasoning in any argument—whether one's own or that of others—be made explicit; analyze the arguments for flawed assumptions, flawed reasoning, or both; and be critical of the claims if any flaws in the argument are found. 12E/H4*

Notice and criticize claims that people make when they select only the data that support the claim and ignore any that would contradict it. 12E/H5*

Notice and criticize claims based on the faulty, incomplete, or misleading use of numbers, such as in instances when (1) average results are reported but not the amount of variation around the average, (2) a percentage or fraction is given but not the total sample size, (3) absolute and proportional quantities are mixed, or (4) results are reported with overstated precision. 12E/H1*

Check graphs to see that they do not misrepresent results by using inappropriate scales or by failing to specify the axes clearly. 12E/H2

Use and correctly interpret relational terms such as *if ... then ..., and, or, sufficient, necessary, some, every, not, correlates with,* and *causes.* 12D/H5

Notice and criticize arguments in which data, reasoning, or claims are represented as the only ones worth considering, with no mention of other possibilities. 12E/H6a*

Consider whether some event of interest might have occurred just by chance. 12E/H3*

6-8

Be skeptical of claims based on very small samples or biased samples. 12E/M3*

Be skeptical of arguments in which all members of a group (such as teenagers or chemists) are implied to have nearly identical characteristics that differ from those of other groups. 12E/M5e

Notice and criticize the reasoning in arguments in which the claims are not consistent with the evidence given. 12E/M5b*

Notice and criticize the reasoning in arguments in which fact and opinion are intermingled. 12E/M5a

Be skeptical of claims based only on analogies. 12E/M5c*

Notice and criticize the reasoning in arguments in which no mention is made of whether control groups are used or whether the control groups are very much like the experimental group. 12E/M5d*

Question claims based on vague attributions (such as "Leading doctors say...") or on statements made by celebrities or others outside the area of their particular expertise. 12E/M1

3-5

Recognize when comparisons might not be fair because some conditions are not kept the same. 12E/E2

Buttress their statements with facts found in books, articles, and databases, and identify the sources used and expect others to do the same. 12E/E1

Offer reasons for claims and consider reasons suggested by others. 12A/E2*

Seek reasons for believing something rather than just claiming "Everybody knows that ... " or "I just know" and discount such claims when made by others. 12E/E3*

K-2

Ask "How do you know?" in appropriate situations and attempt reasonable answers when others ask the same question. 12E/P1*

HABITS OF MIND

COMMUNICATION SKILLS (12D)

Discourse in science, mathematics, and technology calls for the ability to communicate ideas and share information with fidelity and clarity and to read and listen with understanding. Some of the skills involved are specific to science, mathematics, and technology, and others are general—although even those are not independent of content.

The map is organized around three strands—*mathematical communication, visual communication,* and *oral and written communication*. In the elementary grades, the focus is on describing and interpreting descriptions of objects and events, including descriptions using simple tables and graphs. In middle school, the focus is on interpreting graphic and symbolic representations of data and on giving scientific explanations of phenomena. In high school, the focus is on using graphs and equations to represent relationships among objects and events and to make logical arguments about claims.

The map draws on ideas about shapes and their relationships on the **SHAPES** map and ideas about monitoring change on the **PATTERNS OF CHANGE** map.

NOTES

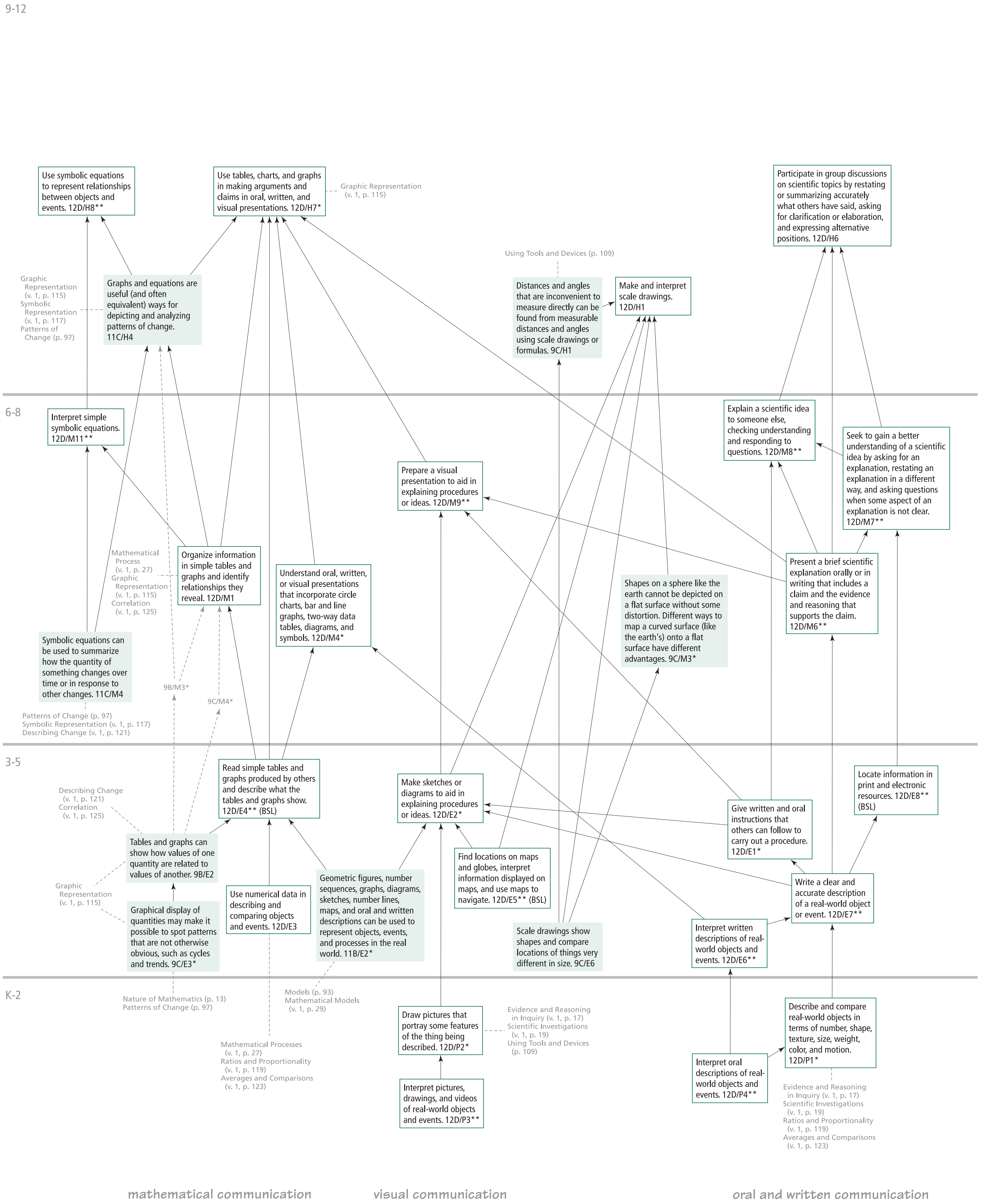
Several benchmarks have been added to this map to provide a more coherent progression of skills over the course of a K-12 education. In the *mathematical communication* strand, these include a new grades 3-5 benchmark "Read simple tables and graphs…" along with new benchmarks on interpreting simple symbolic equations at the middle-school level and on developing symbolic equations at the high-school level.

A benchmark about reading maps and globes in the *visual communication* strand has been moved from the 6-8 to 3-5 grade range to better match expectations in the national standards for social studies and geography. In grades K-2, a new statement "Interpret pictures, drawings, and videos…" has been added as a precursor to a 3-5 benchmark that expects students to make their own accurate representations. A new 6-8 benchmark "Prepare a visual presentation…" calls for students to make use of visualizations in their explanations.

In the *oral and written communication* strand, new benchmarks ask students to interpret oral descriptions in grades K-2 and written descriptions in grades 3-5. The elementary-level benchmark "Locate information in print and electronic resources" describes skills that have become more prevalent among younger students than they were at the time the skills were originally placed at the middle-school level in *Benchmarks for Science Literacy*. Finally, to prepare for the high-school benchmark "Participate in group discussions on scientific topics…," three new prerequisite benchmarks have been added at the grades 6-8 level, including "Present a brief scientific explanation orally or in writing…" and "Seek to gain a better understanding…."

RESEARCH IN *BENCHMARKS*

No relevant research available in *Benchmarks.*



9-12

Use symbolic equations to represent relationships between objects and events. 12D/H8**

Use tables, charts, and graphs in making arguments and claims in oral, written, and visual presentations. 12D/H7*

Graphic Representation (v. 1, p. 115)

Participate in group discussions on scientific topics by restating or summarizing accurately what others have said, asking for clarification or elaboration, and expressing alternative positions. 12D/H6

Graphic Representation (v. 1, p. 115)
Symbolic Representation (v. 1, p. 117)
Patterns of Change (p. 97)

Graphs and equations are useful (and often equivalent) ways for depicting and analyzing patterns of change. 11C/H4

Using Tools and Devices (p. 109)

Distances and angles that are inconvenient to measure directly can be found from measurable distances and angles using scale drawings or formulas. 9C/H1

Make and interpret scale drawings. 12D/H1

6-8

Interpret simple symbolic equations. 12D/M11**

Prepare a visual presentation to aid in explaining procedures or ideas. 12D/M9**

Explain a scientific idea to someone else, checking understanding and responding to questions. 12D/M8**

Seek to gain a better understanding of a scientific idea by asking for an explanation, restating an explanation in a different way, and asking questions when some aspect of an explanation is not clear. 12D/M7**

Mathematical Process (v. 1, p. 27)
Graphic Representation (v. 1, p. 115)
Correlation (v. 1, p. 125)

Organize information in simple tables and graphs and identify relationships they reveal. 12D/M1

Understand oral, written, or visual presentations that incorporate circle charts, bar and line graphs, two-way data tables, diagrams, and symbols. 12D/M4*

Shapes on a sphere like the earth cannot be depicted on a flat surface without some distortion. Different ways to map a curved surface (like the earth's) onto a flat surface have different advantages. 9C/M3*

Present a brief scientific explanation orally or in writing that includes a claim and the evidence and reasoning that supports the claim. 12D/M6**

Symbolic equations can be used to summarize how the quantity of something changes over time or in response to other changes. 11C/M4

9B/M3*

9C/M4*

Patterns of Change (p. 97)
Symbolic Representation (v. 1, p. 117)
Describing Change (v. 1, p. 121)

3-5

Describing Change (v. 1, p. 121)
Correlation (v. 1, p. 125)

Read simple tables and graphs produced by others and describe what the tables and graphs show. 12D/E4** (BSL)

Make sketches or diagrams to aid in explaining procedures or ideas. 12D/E2*

Give written and oral instructions that others can follow to carry out a procedure. 12D/E1*

Locate information in print and electronic resources. 12D/E8** (BSL)

Tables and graphs can show how values of one quantity are related to values of another. 9B/E2

Graphic Representation (v. 1, p. 115)

Graphical display of quantities may make it possible to spot patterns that are not otherwise obvious, such as cycles and trends. 9C/E3*

Use numerical data in describing and comparing objects and events. 12D/E3

Geometric figures, number sequences, graphs, diagrams, sketches, number lines, maps, and oral and written descriptions can be used to represent objects, events, and processes in the real world. 11B/E2*

Find locations on maps and globes, interpret information displayed on maps, and use maps to navigate. 12D/E5** (BSL)

Scale drawings show shapes and compare locations of things very different in size. 9C/E6

Interpret written descriptions of real-world objects and events. 12D/E6**

Write a clear and accurate description of a real-world object or event. 12D/E7**

K-2

Nature of Mathematics (p. 13)
Patterns of Change (p. 97)

Models (p. 93)
Mathematical Models (v. 1, p. 29)

Mathematical Processes (v. 1, p. 27)
Ratios and Proportionality (v. 1, p. 119)
Averages and Comparisons (v. 1, p. 123)

Draw pictures that portray some features of the thing being described. 12D/P2*

Evidence and Reasoning in Inquiry (v. 1, p. 17)
Scientific Investigations (v. 1, p. 19)
Using Tools and Devices (p. 109)

Interpret pictures, drawings, and videos of real-world objects and events. 12D/P3**

Interpret oral descriptions of real-world objects and events. 12D/P4**

Describe and compare real-world objects in terms of number, shape, texture, size, weight, color, and motion. 12D/P1*

Evidence and Reasoning in Inquiry (v. 1, p. 17)
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mathematical communication

visual communication

oral and written communication

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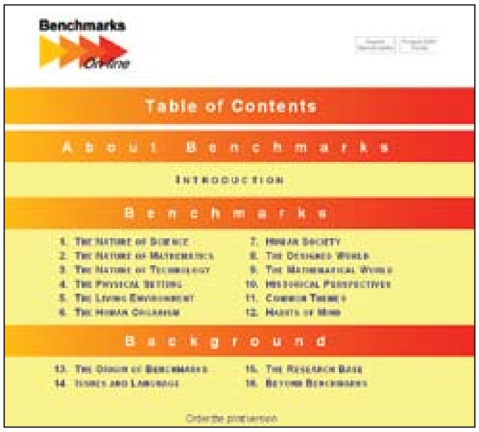

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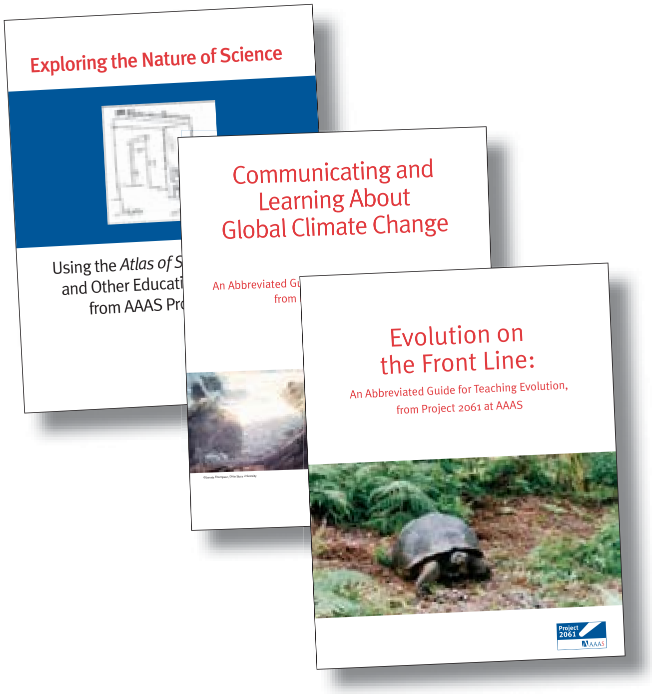

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